Initiation of Alfvénic turbulence by Alfvén wave collisions: a numerical study

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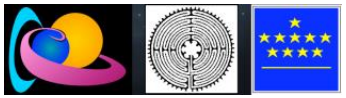

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SIDC, Royal Observatory of Belgium

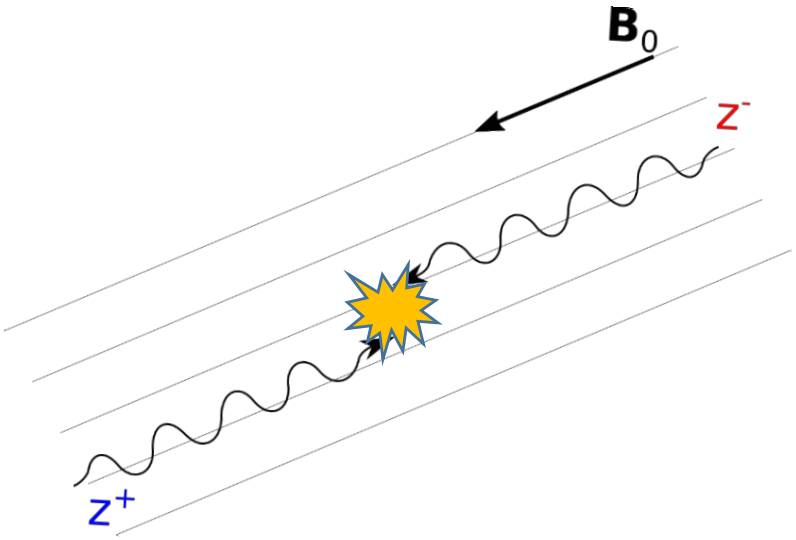
Outline

- Alfvénic turbulence
- Physical conditions
- Numerical setup
- Analysis:
  - Spatial distribution of v;
  - Fourier components;
- Conclusions

Alfvénic turbulence in plasma

Iroshnikov (1963),
Kraichnan (1965)
and followers …
Ng&Battacharge 1996
Howes&Nielson 2013 …

incompr. MHD



- Interaction between counter-propagating AWs;
- $\boldsymbol{z^-} = \boldsymbol{u} - \frac{\boldsymbol{b}}{\sqrt{4\pi\rho}}$
- $\boldsymbol{z^+} = \boldsymbol{u} + \frac{\boldsymbol{b}}{\sqrt{4\pi\rho}}$
- Transfer of energy to smaller ⊥ scales – larger $\boldsymbol{k}_\perp$;

Alfvénic turbulence in plasma

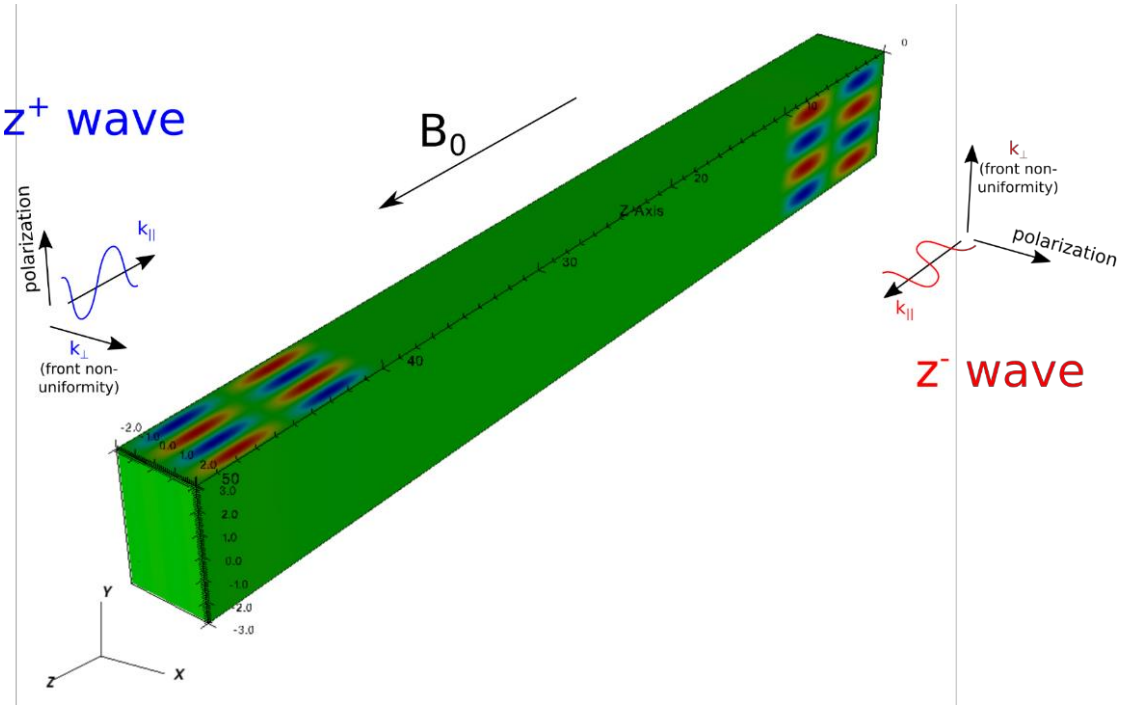
Necessary conditions:

$\boldsymbol{z^-} = \boldsymbol{u} - \frac{\boldsymbol{b}}{\sqrt{4\pi\rho}}$

- $\boldsymbol{k}_{\|}$ towards $\mathbf{B_0}$
- $\boldsymbol{k}_{\perp}$ – nonunif. along y-axis
- zx-polarization

$\boldsymbol{z^+} = \boldsymbol{u} + \frac{\boldsymbol{b}}{\sqrt{4\pi\rho}}$

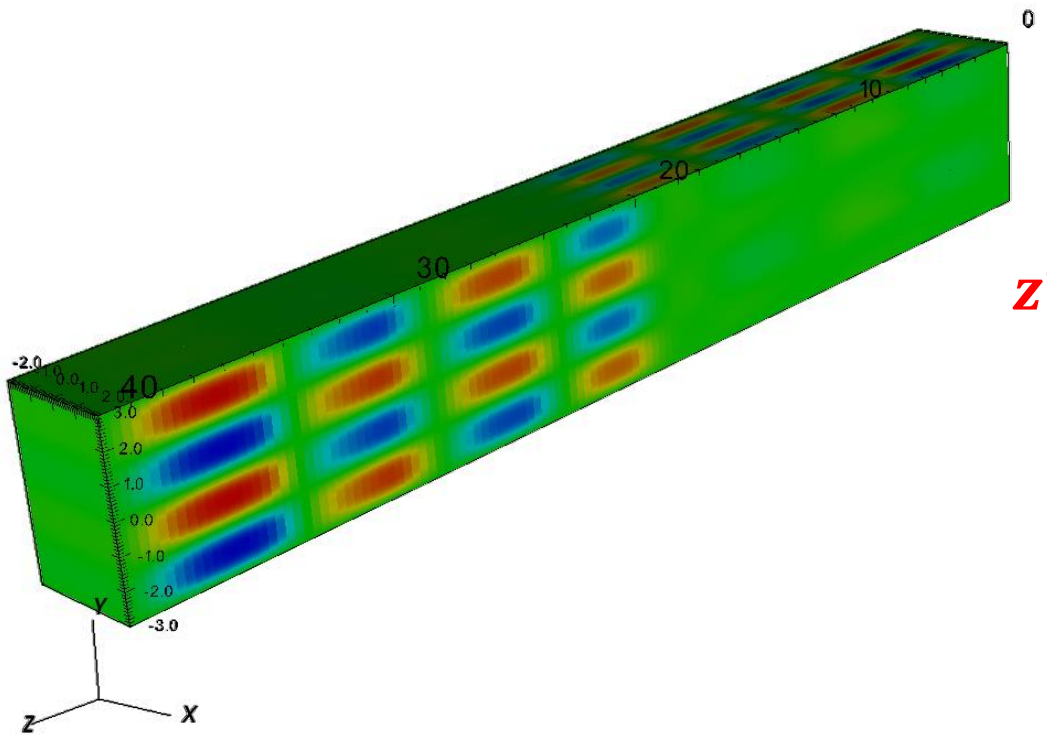
- $\boldsymbol{k}_{\|}$ anti $\mathbf{B_0}$
- $\boldsymbol{k}_{\perp}$ – nonunif. along x-axis
- zy-polarization



Alfvénic turbulence in plasma

Animation

$$z^{+} = u + \frac{b}{\sqrt{4\pi\rho}}$$

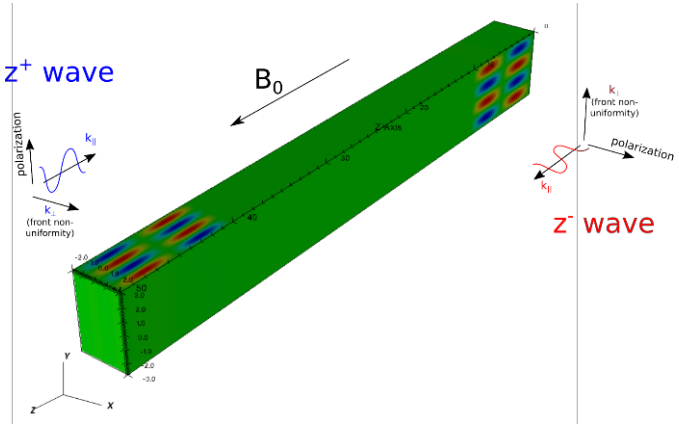


$$z^{-} = u - \frac{b}{\sqrt{4\pi\rho}}$$

Alfvénic turbulence in plasma

Iroshnikov (1963), Kraichnan (1965) and followers

incompr. MHD



- Interaction between counter-propagating AWs;
- $\boldsymbol{z}^{-} = \boldsymbol{u} - \frac{\boldsymbol{b}}{\sqrt{4\pi\rho}}$
- $\boldsymbol{z}^{+} = \boldsymbol{u} + \frac{\boldsymbol{b}}{\sqrt{4\pi\rho}}$
- Transfer of energy to smaller ⊥ scales – larger $\boldsymbol{k}_{\perp}$;

MHD eqs. -> Elsasser form

$$\frac{\partial z^{\pm}}{\partial t} \mp (\boldsymbol{v}_A \cdot \nabla) z^{\pm} + \left(z^{\mp} \cdot \nabla\right) z^{\pm} = -\frac{\nabla P}{\rho_0}$$

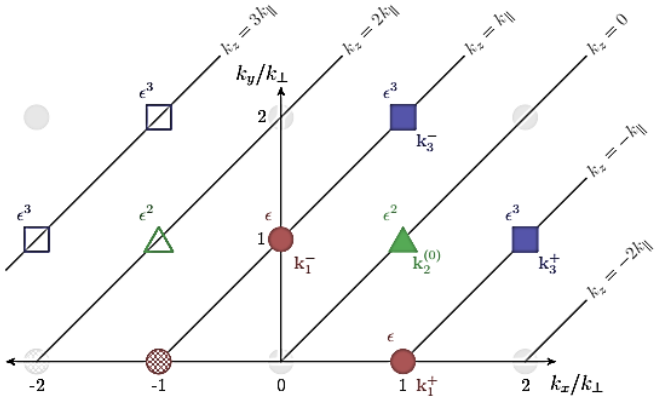
…

$$k_{\perp}^{+} + k_{\perp}^{-} = k_2^{(0)}$$

$$k_{\perp}^{\pm} + k_2^{(0)} = k_{\perp 3}^{\pm}$$

Efficiency should depend on:

- Relative scales $\lambda_{\parallel}$ and $\lambda_{\perp}$;
- Amplitudes z^{+} and z^{-};



From Howes & Nielson 2013

Numerical setup

- MPI-AMRVAC, 3D MHD
  - B_0 =20 Gauss
  - n_e=10^9 cm^{-3}
  - T = 1 MK;
  - υ_A = 1 380 km/s;
  - β = 0.017;

L_z=50 Mm; L_x,L_y = $2\lambda_\perp$;

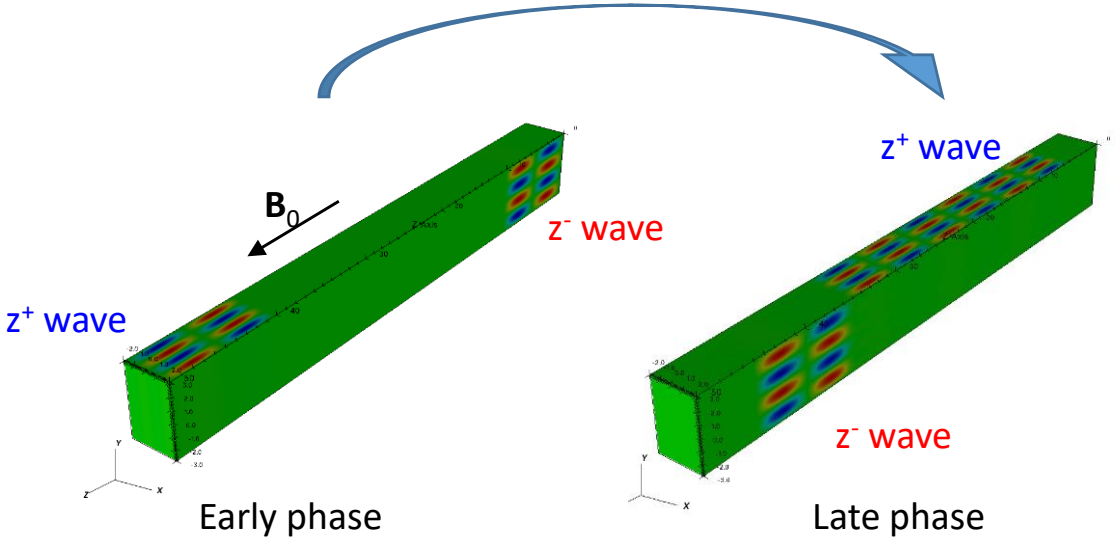
Sensitive to grid size (256x256x512), method (tvdlf, woodward).

- Perturbations:

u = $0.1\upsilon_A$; b = $0.1B_0$;

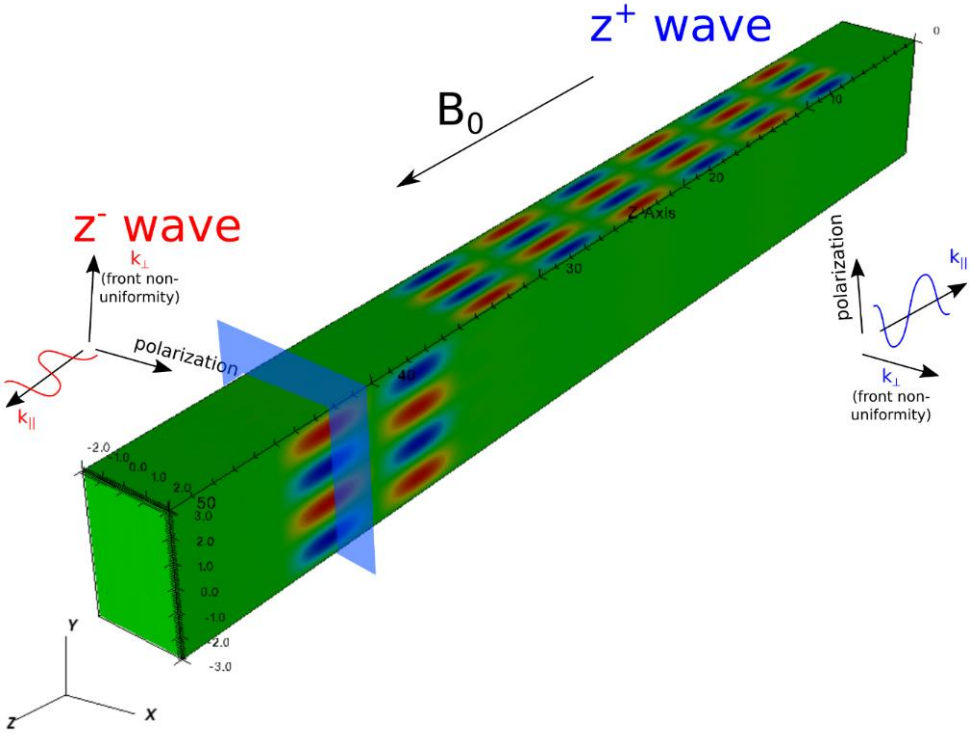
$\lambda_{||}$=10 Mm;

$\lambda_\perp$=0.3, 0.75, 1.5, 7.5, 37.5 Mm;

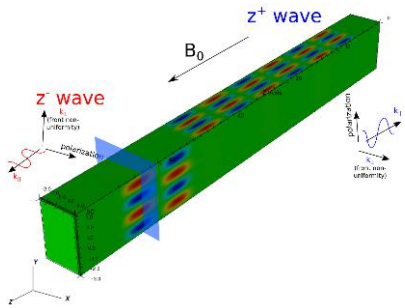


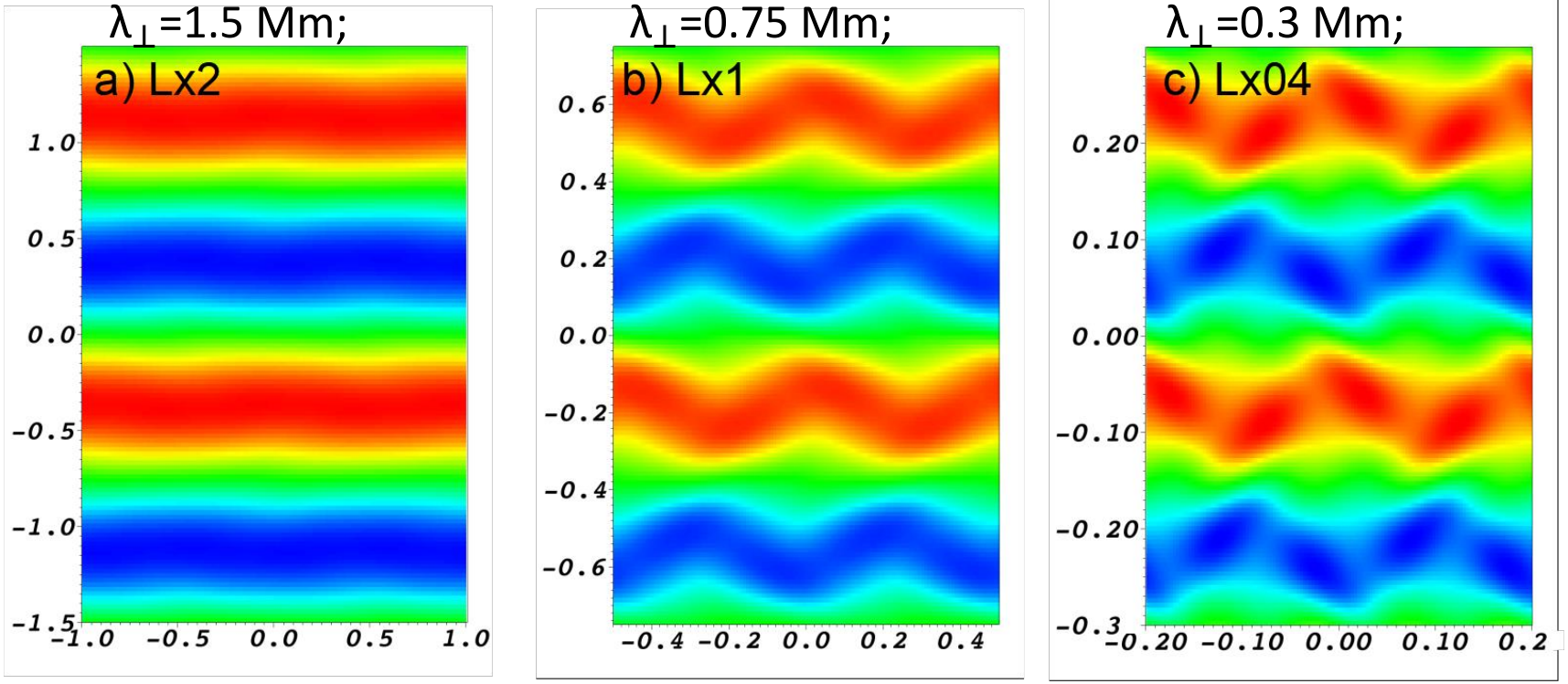
Expected results and possibilities for analysis

Waves with new $\boldsymbol{k}_\perp$ are produced.
They propagate with v_A together with mother waves;



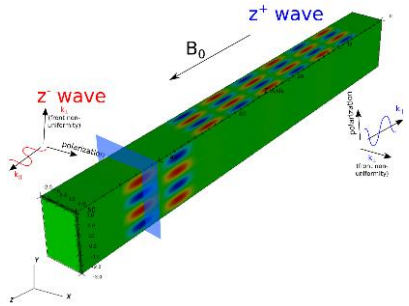
Perturbation of v_x profiles



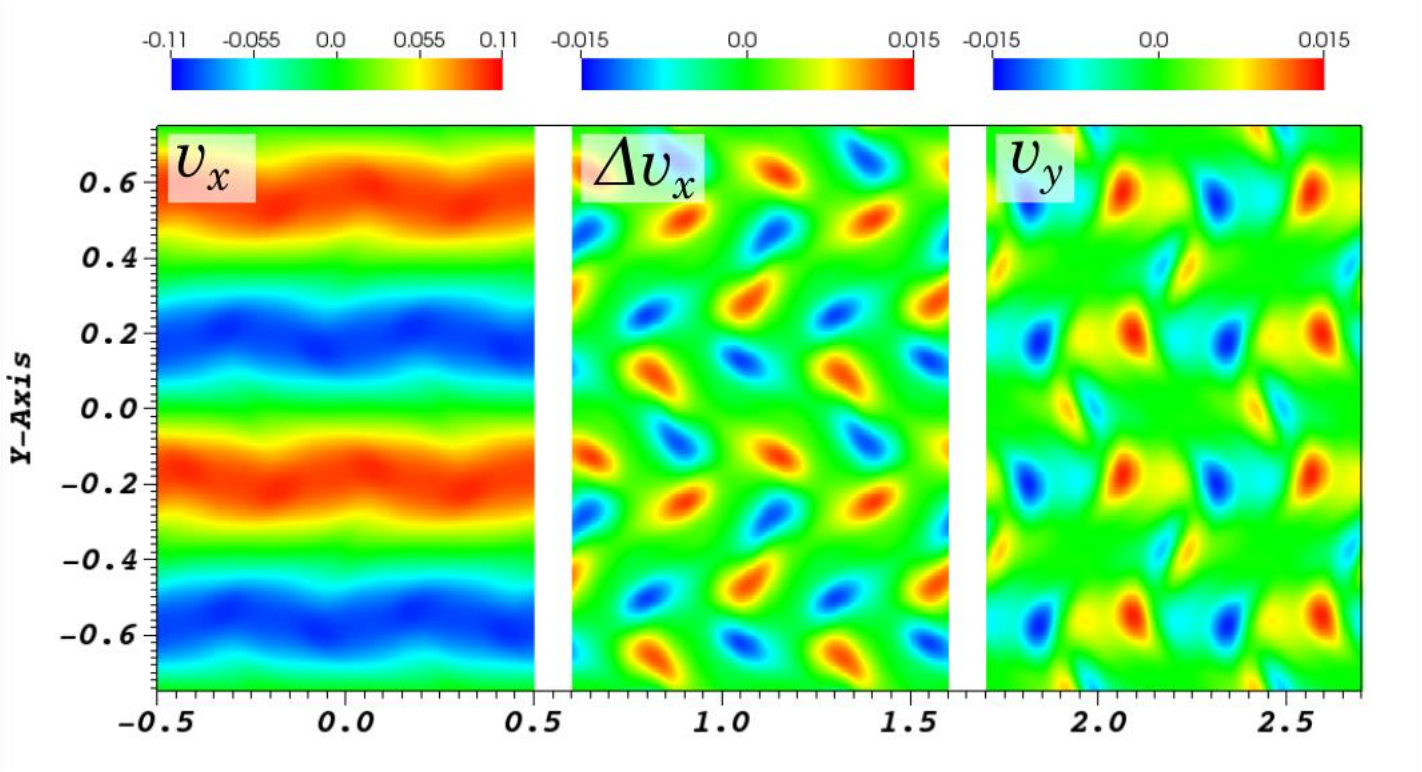


$\lambda_{||}$=10 Mm;

Perturbation of v_x and v_y profiles



$\lambda_\perp$=0.75 Mm;



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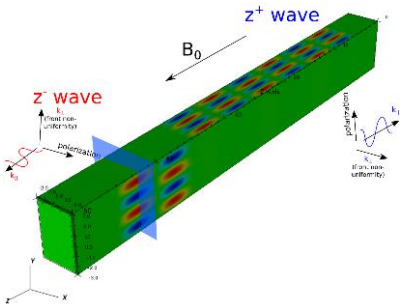

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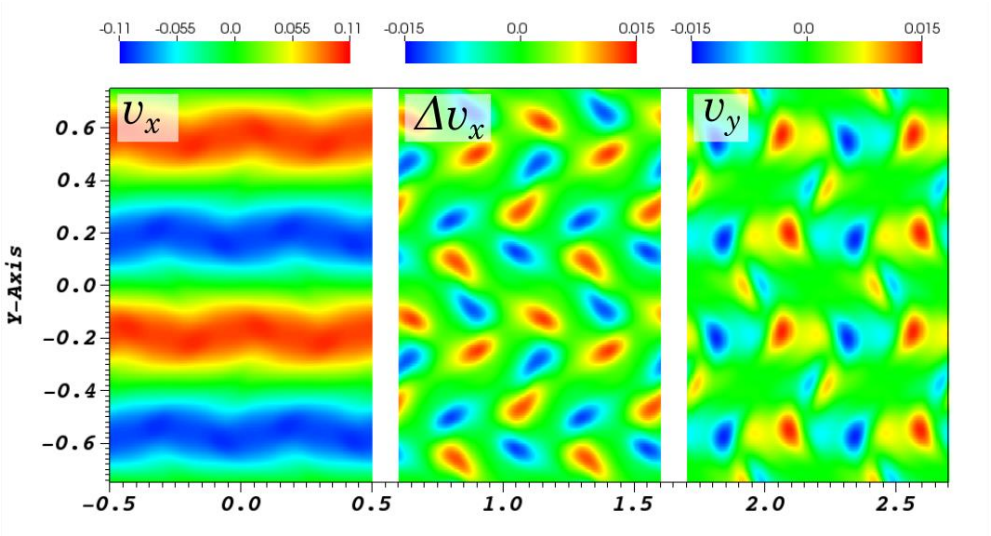
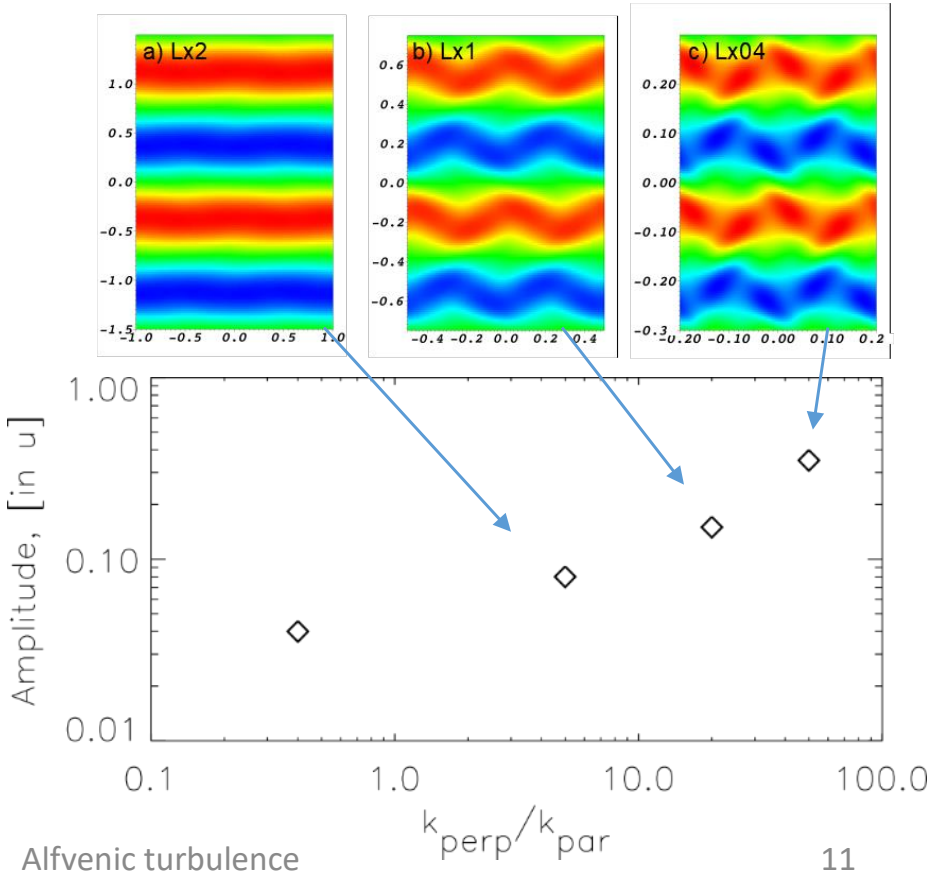
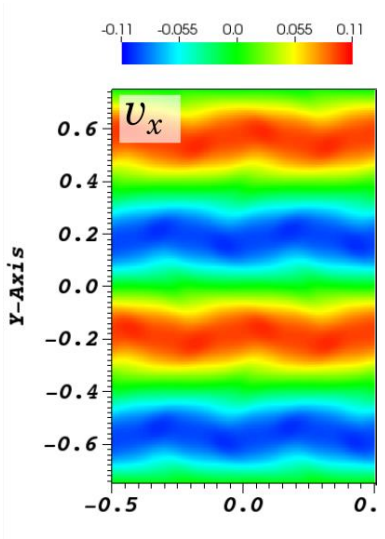
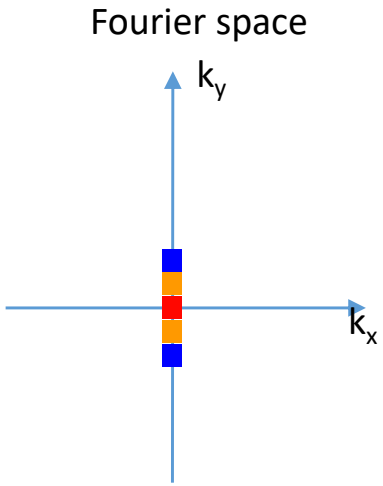
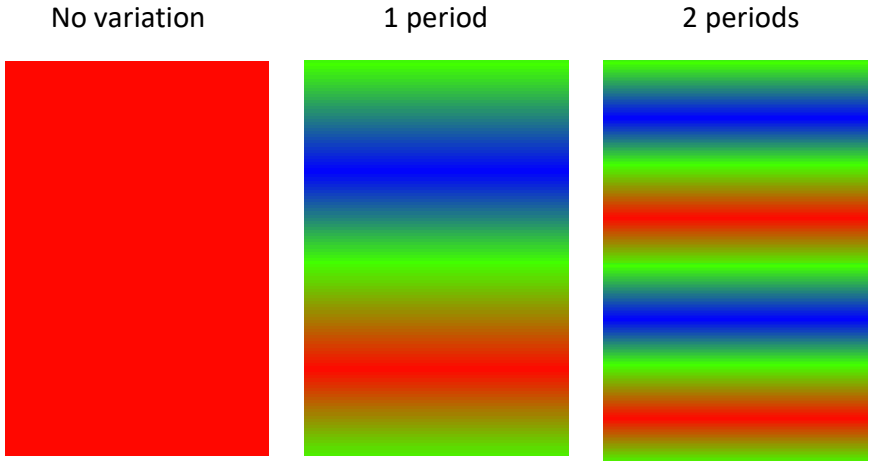




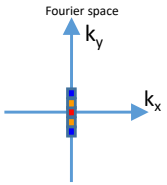
Spectral components

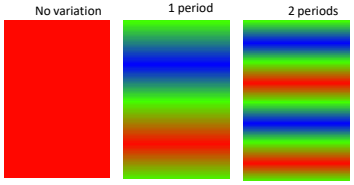






Spectral components



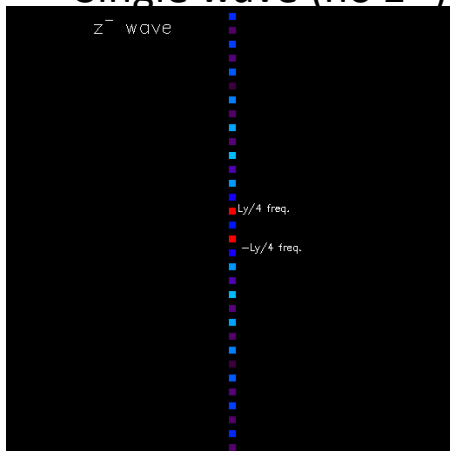


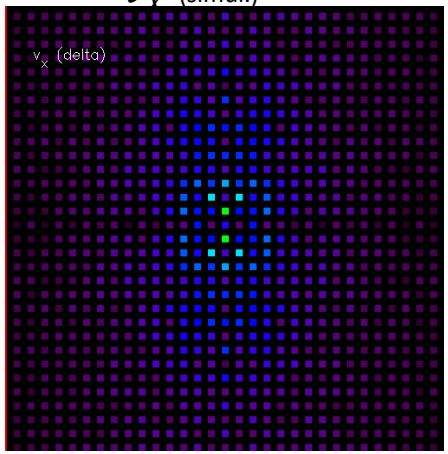
Single wave (no z^+)

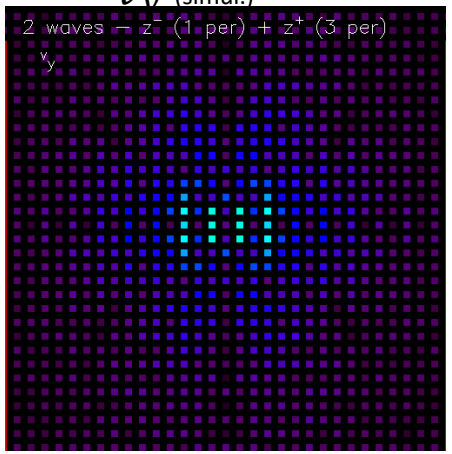
v_x (simul.)

v_y (simul.)

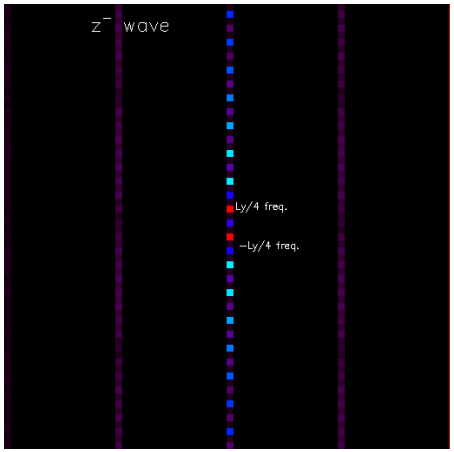
case 1 – large $\lambda_\perp$

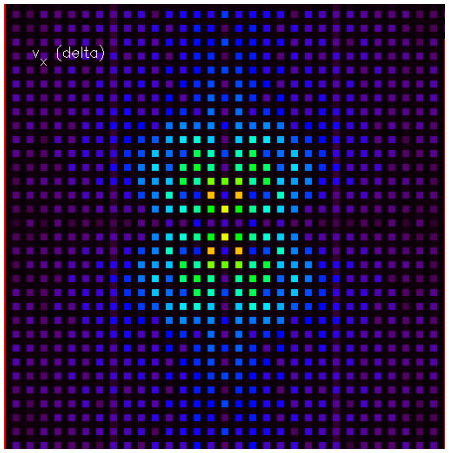


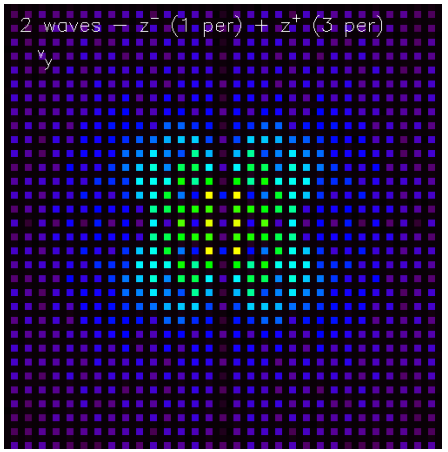


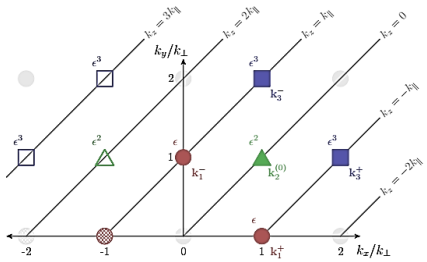


case 2 – small $\lambda_\perp$









Conclusions

- Alfvén wave collisions – interaction of counter-propagating Alfvén waves in MHD;
- Necessary conditions – ⊥ wavefront nonuniformities ($\boldsymbol{k}_\perp$);
- New waves with smaller ⊥ scales are generated (higher $\boldsymbol{k}_\perp$);
- Efficiency depends on ⊥/|| scales;

Thank you for attention!